FORCeS

Air quality and climate policies: Moving forward after COVID-19

This policy brief will answer:

- How were air quality and climate affected during COVID-19?
- How will air quality and climate be affected by after COVID-19 recovery plans?
- What lessons for climate and air quality policies moving forward after COVID-19?

The ultimate aim of the FORCeS project is to understand and reduce the long-standing uncertainty in anthropogenic aerosol radiative forcing. This is crucial if we are to increase confidence in climate projections.

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How much will air quality improve if traffic emissions are halved? If air quality improves, how will this affect climate change? What mix of reductions in the emissions of short-lived climate forcers and greenhouse gases will produce the most desirable air quality and climate outcome? Since it is not possible to conduct large-scale real-life experiments, scientists must make use of complex computer models to answer such questions. In 2020, however, atmospheric scientists were given a unique opportunity to take research outside the laboratory and follow the consequences of an unintended real-life experiment.

On March 11, 2020, the World Health Organization declared the outbreak of COVID-19 a global pandemic. To contain the spread of the virus, restrictions were implemented on the movement of people and on industrial and commercial activities for several months. The restrictions led to rapid and unforeseen reductions in emissions of atmospheric pollutants and greenhouse gases worldwide.

The onset of the pandemic was followed by a wave of research studies towards the detection, attribution, and increased understanding of the impacts of reduced anthropogenic emissions on the Earth's atmosphere and climate. Here we look at some of the findings from these studies, many of them conducted by FORCeS researchers, which not only deepen our understanding of the mechanisms that govern atmospheric composition, air quality, and climate but also hopefully provide guidance for policymakers working towards the improvement of air quality and climate change mitigation.

How were air quality and climate affected during COVID-19?

When the pandemic hit, city streets became quiet and traffic emissions dropped, particularly carbon dioxide (CO_2) and nitrogen dioxide (NO_2) emissions. Pollutants emitted by other sectors, such as methane (CH_4) and ammonia (NH_3) from agriculture, saw smaller or no reductions. These emission reductions contributed to a temporary improvement of air quality in most regions of the world.

Barely a few days after restrictions were implemented, changes in the concentrations of short-lived climate forcers (SLFCs) were already detectable. These changes however were not linear and illustrated the complex relationship between emissions, concentrations, meteorology, and atmospheric chemistry (Figure 1). Studies examining the effect of the COVID-19 containment on air quality had to consider the influence of meteorology and the stringency of lockdown measures[1]. A review of more than 200 published studies, lead by Prof. Astrid Kiendler-Scharr, revealed concentration changes of: −13% to −48% for NO_2, −10% to −33% for $PM_{2.5}$, and 0% to +4% for O_3 (Gkatzelis et al., 2021). Ozone concentration increases were found in highly polluted city areas, where complex chemical reactions in the presence of sunlight and volatile organic compounds limit ozone destruction.

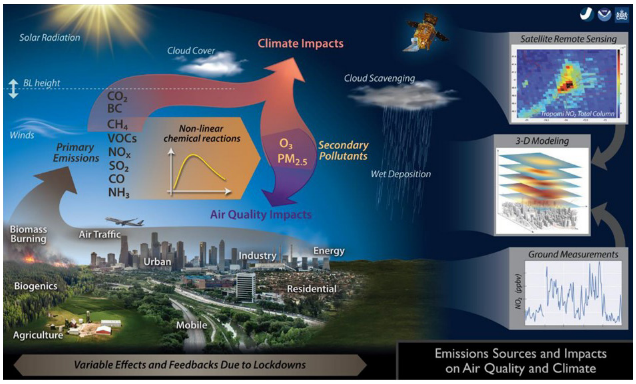
Global fossil CO_2 emissions declined by 7% in 2020 compared to 2019 emissions, roughly the amount needed every year for the next decade to limit global warming to 1.5 °C above pre-industrial levels, consistent with the goal set in the 2015 Paris Agreement. Despite this temporary decline in emissions, the latest analysis of observations from the WMO GAW[2] shows that the concentration of CO_2 in the atmosphere reached a new record high: 413.2 parts per million (almost 1.5 times higher than the pre-industrial levels).

The impact of COVID-19 related emission changes on Earth's energy balance was also investigated: how were weather and climate impacted by reduced emission rates of CO_2 and CH_4, as well as by changes in the abundance of SLCFs? Different chemical species have very different residence times in the atmosphere; from hours to days for aerosols, to decades or longer for well mixed greenhouse gases. Their spatial distribution is also different. For some chemical species, such as aerosols, the highest concentrations are confined to the emission regions. Others, such as CO_2, have almost the same concentrations globally. Therefore, the answer is not at all straightforward.

Several studies, including an international initiative involving 12 Earth system models (Jones et al. 2021), have shown a footprint of COVID-19-related anthropogenic changes in the atmospheric composition as well as the amount of solar radiation reaching the Earth's surface. The peak in the global mean radiative forcing change is different in different studies, but they all agree on the sign and magnitude of the forcing.

In April 2020, the warming effect from a decrease in the aerosol burden was greater than the cooling effect due to decreased GHG emissions and aviation-induced cirrus clouds – although the uncertainty is large (Gettelman et al., 2021). In other words, more radiation reached the surface of the planet, with the peak radiative forcing

1 *https://ourworldindata.org/grapher/covid-stringency-index*
2 *https://public.wmo.int/en/media/press-release/greenhouse-gas-bulletin-another-year-another-record*



change estimated to be between +0.025 and +0.2 Wm^{-2}, i.e, between 1% and 7% of the human-caused radiative forcing estimate presented in the AR6 WGI Summary for Policymakers[3]. However, by the end of 2021, this value had been reduced to half. In summary, this is a small radiative forcing change and no detectable change in the atmospheric CO_2 concentration, surface temperature, rainfall or any other regional or global climate parameter has been found.

Figure 1. Schematic of major emission sectors and primary emissions, meteorological and chemical processes, impacts to air quality and climate (Gkatzelis et al. 2021).

SLCFs | Short lived climate forcers (SLCFs) are atmospheric pollutants which affect the climate but, unlike e.g. CO_2, they remain in the atmosphere for only a few days to years. SLCFs include aerosols and gases such as ozone and nitrogen oxides but also methane which persists in the atmosphere for around a decade. SLCFs affect the climate predominantly in the first two decades after their emission or formation, and can have either a cooling or warming effect on climate[4]. From a climate policy perspective, the interest in methane has recently increased as reducing its emissions might be the only way to limit near-term warming. A recent study by Forster et al. (2020) using simple climate models, shows that cutting methane emissions by 50% will reduce global warming by 0.2˚C by 2050. These results support the Headline Statements from the AR6 WG1 Summary for Policymakers, which concluded that “Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality”.

Aviation-induced cirrus clouds | As they fly at their cruise height, airplanes leave vapor trails (also known as contrails) which can lead to the formation of cirrus clouds. Cirrus are high-altitude clouds that allow sunlight to enter the atmosphere while absorbing and reemitting infrared radiation from the Earth’s surface. Aviation can therefore contribute to an increase in cloudiness at high altitudes and thus a warming of the Earth. Quantifying the magnitude of this contribution has proven challenging. The reduction in air traffic in response to the COVID-19 outbreak (about 70% in large regions) offered an unprecedented opportunity to identify the aviation contribution to the observed cirrus coverage and thickness. Through analysis of satellite observations for the period March–May 2020, FORCeS PI Prof. Johannes Quaas and colleagues (2021) concluded that the cirrus fraction was reduced by 9 ± 1.5% on average relative to a normal air traffic situation. The change in cirrus translates to a global radiative forcing of 61 ± 39 $mW.m^{-2}$, roughly 2% of the human-caused radiative forcing estimate presented in the AR6 Summary for policy makers.

How will air quality and climate be affected by after COVID-19 recovery plans?

As discussed above, the climate effect of the COVID-19-related restrictions were close to negligible. Now, many see in post COVID-19 recovery packages the opportunity for a green recovery paving the way towards a low-carbon society. Forster and colleagues (2020) established a baseline emission scenario where countries are assumed to meet their stated nationally determined contributions (NDCs) by 2030 and from that derived a fossil-fuelled recovery scenario and two different green recovery scenarios (Figure 2a). To assess the effect of different recovery scenarios on climate, a coordinated intercomparison of Earth system model simulations was put together – CovidMIP (Jones et al., 2021).

Figures 2b and 2c show the multi-model mean change in temperature and Arctic sea-ice minimum relative to pre-industrial conditions. The 4 lines in each figure show the results for the baseline (following SSP2-4.5 in CMIP6) and the three CovidMIP recovery scenarios, respectively. Under the green recovery scenarios the warming in mid-century is less strong than the baseline which also results in a reduced decrease of the Arctic

3 https://www.ipcc.ch/report/ar6/wg1/#SPM
4 https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_06.pdf

sea-ice minimum. However, the reduction in warming and sea-ice decline are only a correction to the trends in the baseline and do not stop the on-going warming or melting of sea ice. Nevertheless, the reduction in the warming demonstrates economic recovery pathways can make a valuable contribution towards reaching the goals of the Paris Agreement. Figure 3 illustrates the spatial differences between the strong green recovery scenario and the baseline scenario over Europe as simulated by one Earth system model, showing the potential to reduce daily maximum temperatures. Box 3 presents an example of the further use of CovidMIP simulation results to look at possible benefits of a green recovery in terms of health impacts, most specifically on the reduction of Tick-borne encephalitis (TBE).

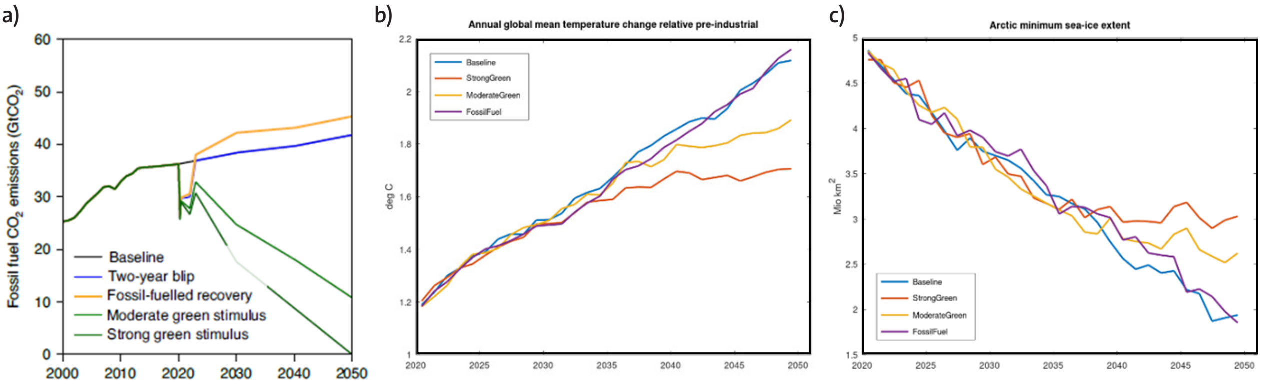


Figure 2. a) Fossil-fuel CO_2 emissions to assess the climate responsible for alternative recovery scenarios (Forster et al. 2020); b)–c) Annual global mean temperature change and Arctic minimum sea-ice extent for alternative recovery scenarios (ensemble mean of 6 Earth system models participating in the CovidMIP). Graphs by Klaus Wyser (SMHI), unpublished.

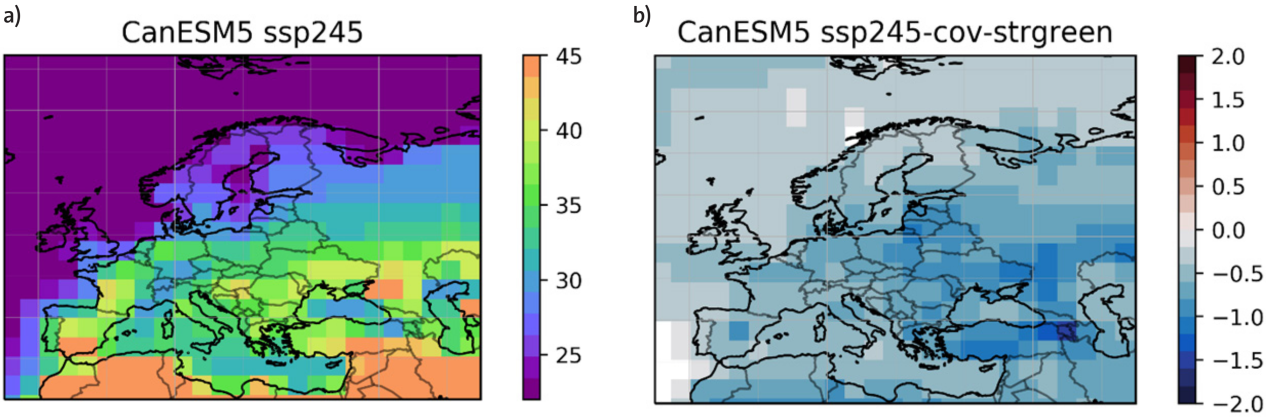


Figure 3. Daily maximum temperatures for alternative recovery scenarios for 2041–2050 (results obtained with one Earth system model as representative of CovidMIP results): a) baseline b) differences between the strong green recovery and the baseline scenario. Images by Ramón F. Franco (SMHI), unpublished.

Currently, only about a quarter of the world population enjoys clean air (according to the 2005 World Health Organization air quality guidelines). Over a third is exposed to concentrations above the WHO Interim target 1 (35 μg/m^3), and more than half lives in areas exceeding the national ambient air quality standards for $PM_{2.5}$ (fine particles smaller than 2.5 μm). In the framework of a study conducted at IIASA for IEA's World Energy Outlook 2021[5], FORCeS' IIASA research team looked at the impact of different emission scenarios on population exposure to $PM_{2.5}$. Figure 4 illustrates the differences in populations exposed to different concentrations of $PM_{2.5}$ under alternative emission scenarios, including deep decarbonization futures. Already in the short term (by 2030), the Net Zero scenario would halve the population exposed to concentrations above 35 μg/m^3 in comparison with the existing legislation scenario. In the long term (by 2050), the Net Zero scenario could lead to a doubling the population living within the WHO guideline (from around 2.2 billion to almost 5 billion people) and reduce the number of exposed to levels above 35 μg/m^3 from almost 4 billion to less than 1 billion compared with the scenario with existing legislation. Pledges announced recently in the scope of COP26, although still short of the Paris Agreement goals, will further decrease the population affected by higher concentrations of $PM_{2.5}$ (not calculated at the time of publication of this policy brief).

5 https://www.iea.org/reports/world-energy-outlook-2021

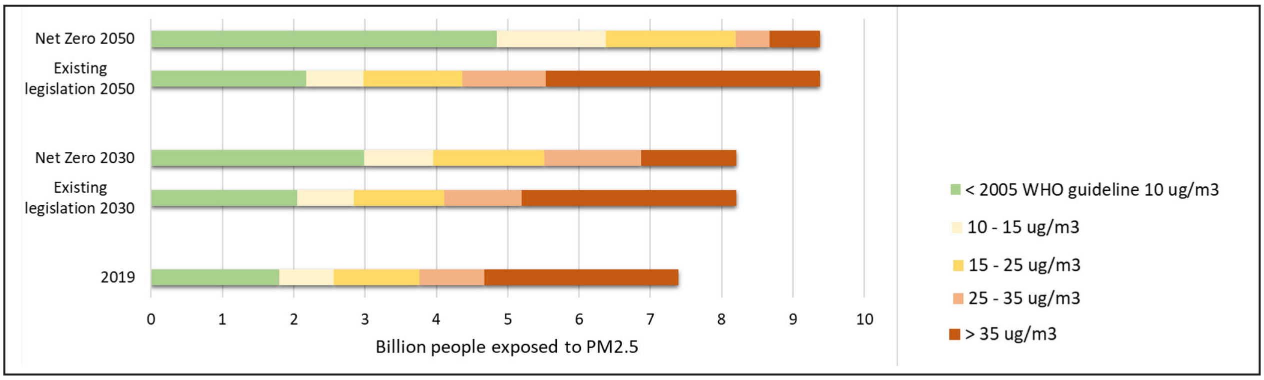


Figure 4. World population exposed to different ambient concentrations of $PM_{2.5}$ under a Stated Policies Scenario (corresponding to policies currently implemented), and the Net Zero Scenario, in 2030 and 2050. Source: GAINS model (IIASA), WEO (IEA, 2021) – graphs by Zbigniew Klimont (IIASA), unpublished.

TBE incidence under after-covid recovery scenarios | Tick-borne encephalitis (TBE) is a viral tick-borne infectious disease. In Europe the main risk areas are central and eastern Europe and the Baltic and Nordic countries. In recent decades, the number of TBE cases in Europe has increased, with endemic areas spreading northwards and to higher altitudes (ECDC, 2021). Reasons for this increase include climate and socio-economic changes but also greater public awareness and improved reporting and diagnosis. An increase in TBE incidence has been found to be related to the occurrence of mild winter seasons. In contrast, winter days with cold temperatures (<–10˚C) in the year previous to the incidence year, are found to decrease TBE incidence since it is when the more cold-sensitive larvae hibernate (Lindgren & Gustafson, 2001). CovidMIP simulations were used to assess changes in the number of days with cold winter temperatures (<–10˚C). The differences in the number of days with minimum temperature colder than –10˚C between the baseline and the scenarios derived by Forster et al. (2020) were calculated. For the strong green scenario, four models show significant differences in Nordic and eastern European countries, with 4 to 9 more days with minimum temperature colder than –10˚C per winter over these areas when compared to the baseline scenario. This result might be translated to a lower TBE incidence in the strong green scenario compared to the baseline.

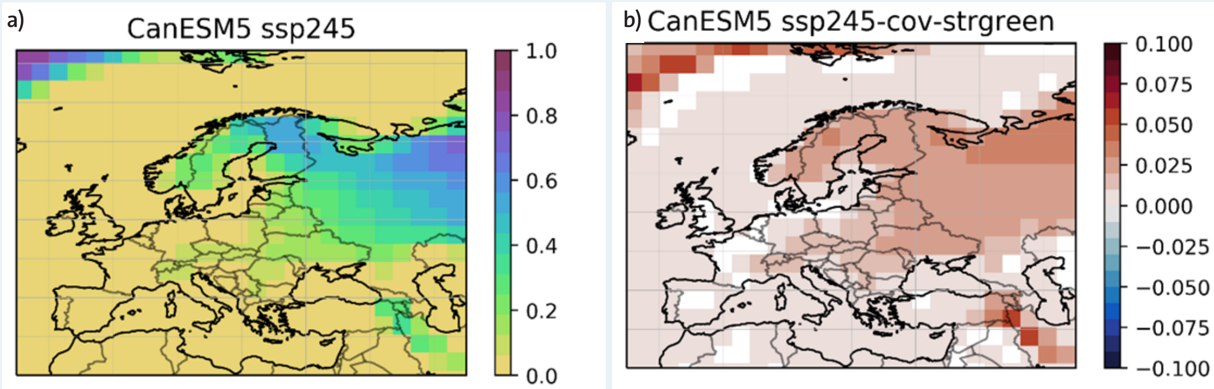


Figure 5. a) Average ratio of the number of days with minimum temperature colder than –10˚C to the total number of winter (Dec–Feb) days for the 2040–2050 period in baseline scenario (1 means that all winter days have a minimum temperature lower than –10˚C. b) differences between the strong green recovery and the baseline scenario. Results obtained with one Earth system model for illustration of CovidMIP models). Images by Ramón F. Franco (SMHI), unpublished.

What lessons for climate and air quality policies moving forward after COVID-19?

A FORCeS stakeholder workshop was held as a webinar on November 8 2021 with the purpose of discussing the impacts of the COVID-crisis in air quality and climate, with a focus on the lessons moving forward. A panel discussion was held with the moderation of Hanna Nikkanen (Journalist, Co-founder of Long Play) and the participation of: John Hassler (Institute for International Economic Studies at Stockholm University), Franz Immler (European Climate, Infrastructure and Environment Executive Agency – CINEA), Astrid Kiendler-Scharr (Forschungszentrum Jülich), Torben Königk (Swedish Meteorological and Hydrological Institute – SMHI), and Joacim Rocklöv (Umeå University). We here summarize and compile the main outcomes of the discussion.

- **Emission changes led to temporary air quality improvements but had almost no impact on climate.** These emission changes observed during the COVID-19 crisis were a consequence of stay-at-home orders designed to limit the spread of the disease, never targeted to improve air quality or to have a positive effect on climate.

- **Larger, sustained changes are needed and can only be achieved through structural changes.** The way forward to emission reductions is not the COVID-way, energy use can no longer be parallel to GDP in the future. Due to the co-emission of SLCF and CO_2, while in the short-term a reduction of GHG and air pollutants emissions might lead to warming effect (as we have just witnessed during the COVID-crisis due to the decrease in aerosols and their precursors), in the long-term climate implications will be dominated by CO_2 effects leading to a decrease of the warming.

- **The data collected during the COVID-19 lock-downs will be used for many years to come to help us better understand the complex mechanisms of atmospheric chemistry,** including the importance of accounting for meteorological conditions, and the effects of emission reductions on air quality and climate. The data will be used to benchmark our climate and air quality models, contributing to their validation and identifying where they perform correctly and where the largest uncertainties remain. This data will ultimately help in the definition of better air quality and climate policies.

- Most of the data collected during the lockdowns are either from remote sensing satellites or routine measurements that are often not as detailed in terms of atmospheric species composition as needed by researchers. Also, despite the importance of CO_2 emissions for understanding and mitigating global climate change, there is no system in place to monitor global emissions in real time. **There is a clear need of better monitoring, for tools allowing for a quick assessment of emission changes and its consequences, and improvement of inventory methodologies.** This goes hand in hand with the need for more elaborate ways of open science and open data, to assure that the knowledge (data and tools) is available and quickly communicated.

- **The need for better tools extends to the modelling field, namely the improvement of Earth system models.** These are essential tools for the study of climate which have been continuously developed to better describe Earth-system-processes and provide greater spatial detail. However, in order to better support climate and air quality policies further, developments are needed that: i) tackle the aspects of climate that affect society and ecosystems and that arise many times from small scale or short-duration extreme events, as well as tipping points and abrupt changes; ii) reduce uncertainties in the estimation of the remaining carbon budget; iii) better incorporate natural and human systems to explore and understand the interactions between climate change, societal change and ecosystem response.

- **Many see, in post COVID-19 recovery packages, the opportunity for a green recovery, however these packages will not and should not replace climate policies.** Climate policies were in place before COVID-19 and have accelerated independently of COVID-19. The global widespread adoption of emission trading schemes and carbon taxes, covering all the major emitting sectors, is key to the realization of the Paris Agreement. The recovery plans can help pave the way towards a low-carbon society, as is the case of the Next Generation EU recovery plan where 30% of the EU funds have to be used in climate change adaptation and mitigation measures. However, the recovery plans may also lesson the likelihood of achieving climate goals if governments prioritize a fossil-fuel based economy restart.

- **The pandemic has also provided many learning opportunities for public health.** As for climate and air quality, the data collected during this period will be used for many years to come not only in studies related to the COVID pandemic but also with other diseases such as flue or dengue. The COVID-crisis and the climate crisis have some common roots, such as deforestation and destruction of habitats. As such, these problems should have common solutions. Changing behaviours is very important for public health, the same is true for climate change.
- **The COVID-19 crisis has provided a new context, showing us that change is possible and can happen quickly.** It has highlighted that we are flexible and adaptable in the way we organize our lives, and that cities with less cars, less noise and less pollution are healthier cities. Having experienced first-hand the benefits of emission reductions citizens may be more willing to accept climate policies such as carbon taxing.
- **The nexus between climate, air quality and health need to be better explored and communicated** both to citizens and those responsible for the development of policies towards the transition to a carbon-neutral economy (e.g. it's not just about the temperature per se, it's also about air quality and health). Air pollution is the number one environmental health risk. As such, emphasising the health benefits in the context of improved air quality, as a consequence of carbon emission reductions is a strong way forward.
- **Moving forward requires an interdisciplinary approach, where the links between health, air quality and climate change are explored.** We need to be able to tell ONE story, a story about societal transformation, where the integration of economic, air quality, climate and health policies leads to short-term benefits for air quality and health, and long-term benefits for climate, at the regional and global levels.

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FORCeS in numbers

22	12	3	3	151	68
Organizations	European countries	European Earth System Models	Campaigns conducted within/during	Researchers	Early career researchers

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